

A Unified Approach to Modeling Multidisciplinary Interactions

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Slides are available from MDOB web site:

<http://fmad-www.larc.nasa.gov/mdob/MDOB>

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Outline

- Background, motivation & issues
- Available techniques
- Unified approach (transformation matrices + CAD)
- Results
- Concluding remarks & future work

Background

(relevant to this work)

- Commercially developed tools
 - FLEXSTAB developed by Boeing under NASA funding in sixties and seventies
 - Elfini developed by Dassault (based on an intermediate computational surface)
- Current research efforts
 - Interpolation-based algorithms developed by Maman & Farhat, Cebral & Löhner,...
 - NURBS-based approach developed at NASA by Samareh
- Boeing & NASA-LaRC plan to develop a CAD-based tool for industrial application

Desirable Characteristics

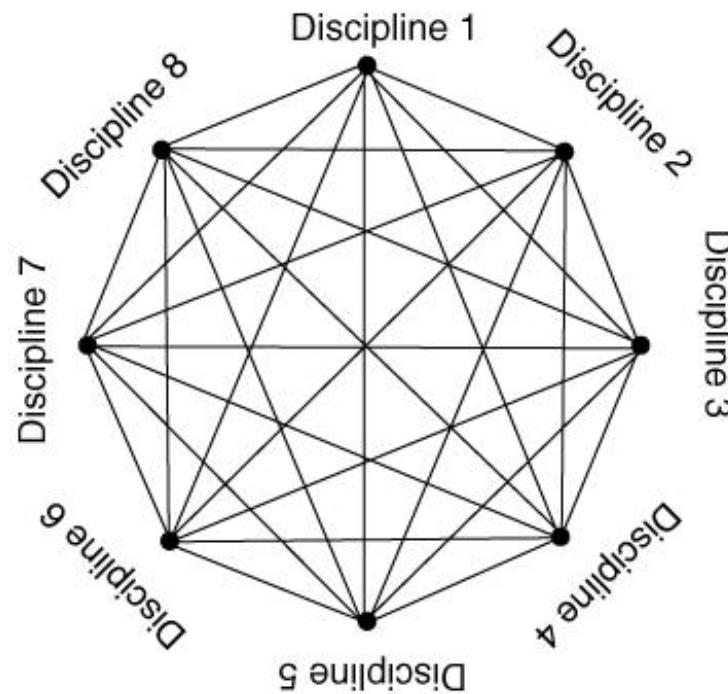
- Be **consistent** across disciplines
- Be suitable for **industrial** design settings
- Be based on **CAD**
- Be suitable for modeling **large** number of interactions
- Handles **dissimilar** grids with large **discrepancies** in resolution
- Handles **different levels** of geometry details
- Deal with scalar (e.g., Pressure & Temperature), vector (e.g., deflection & heat flux), or integrated (e.g., forces & moments) quantities
- Deal with constraints (e.g., **conservation** & consistency)

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Large Number of Interactions

Disciplines such as:

1. CFD
2. FEM
3. Wind tunnel
4. Aerothermal
5. Propulsion
6. ..

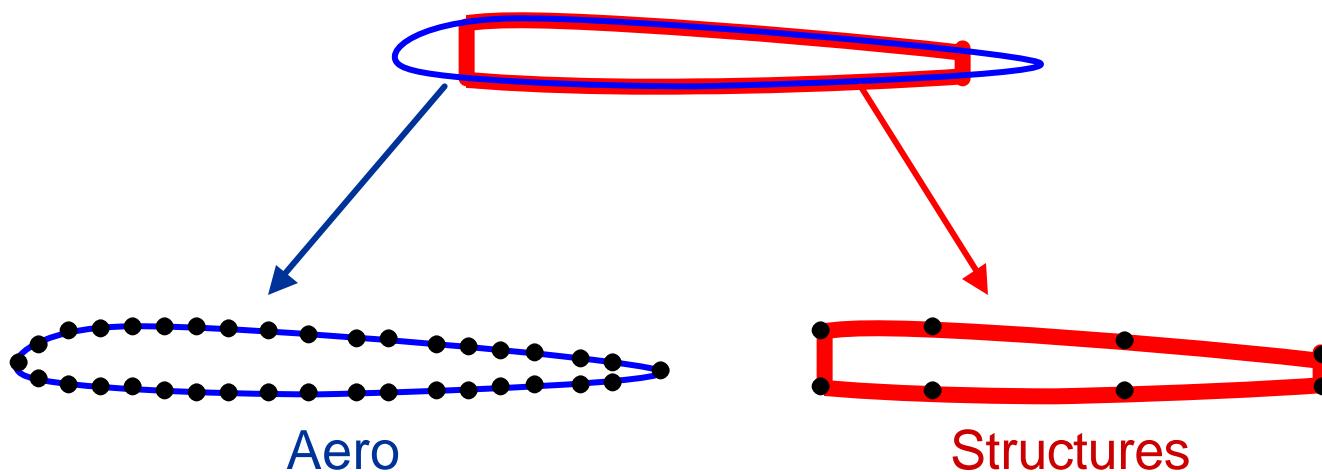


$N(N-1)$ Interactions
For $N = 8$, there are 56 interactions

Dissimilar Grids With Large Variations in Grid Size

Discipline grids often :

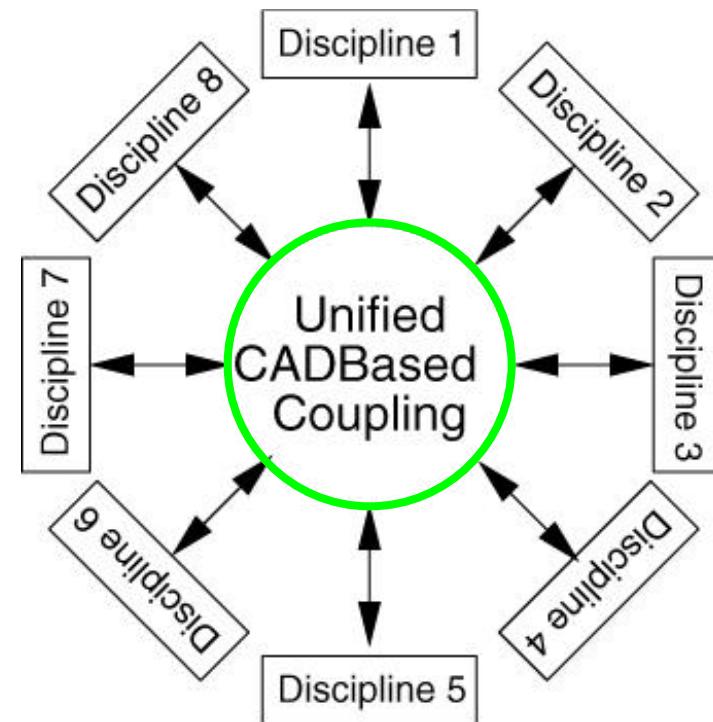
- Have dissimilar grids (different grid points and topologies)
- Have large variations in grid sizes
- Have different levels of geometry details



Unified Approach to Modeling Multidisciplinary Interactions

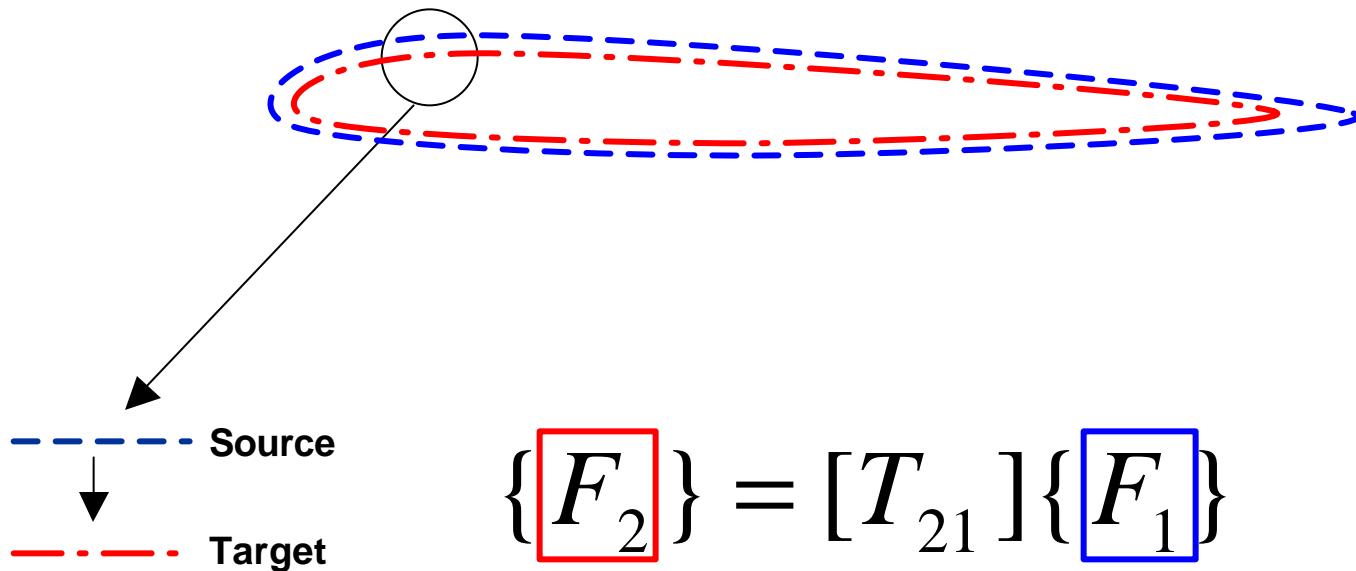
(Transformation Matrix + CAD)

- Reduce number of interactions
- Unify interactions
- Use CAD
 - Surface model or tessellated
 - Consistent data representation
 - Suitable for industrial settings
 - Dissimilar grids
 - Different levels of geometry details

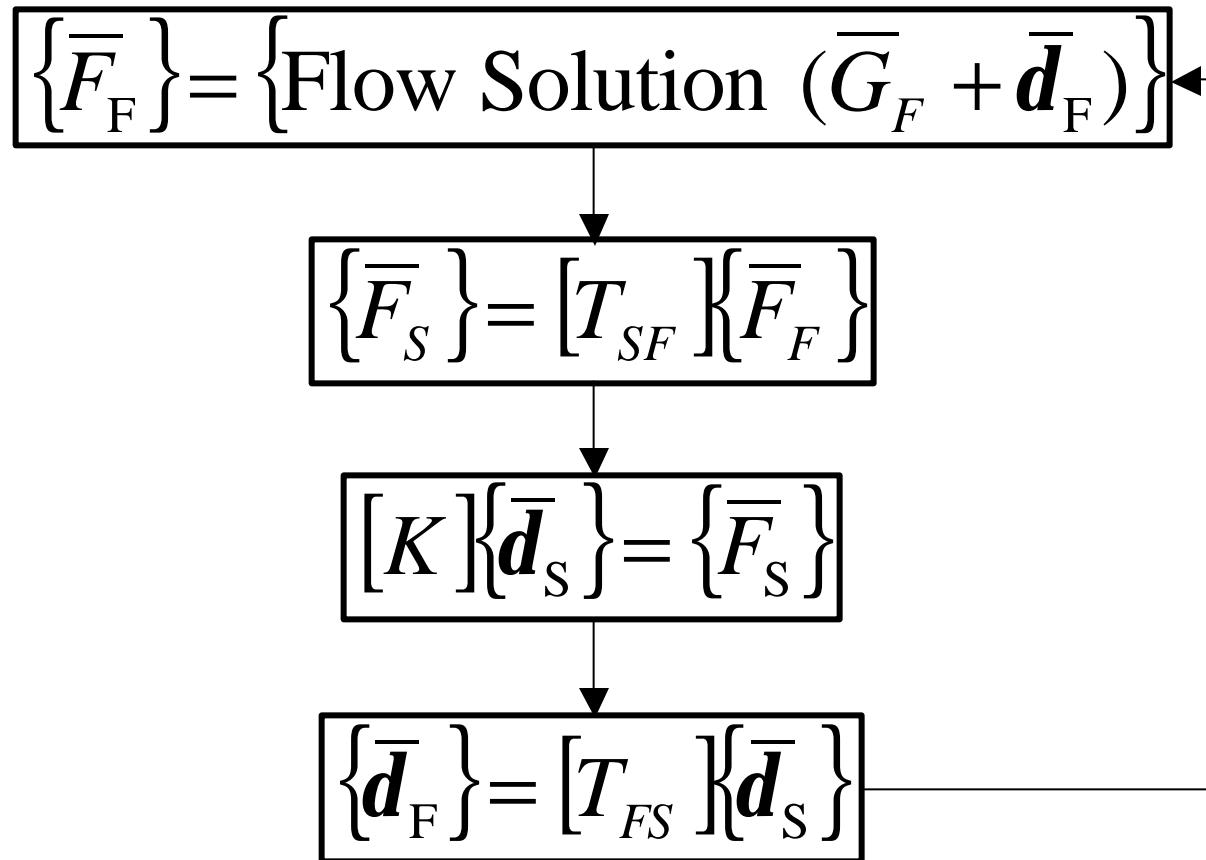


Unified Approach to Modeling Multidisciplinary Interactions

(Transformation Matrix)



Examples (Aeroelastic)



Examples (Sensitivity Analysis)

design variables

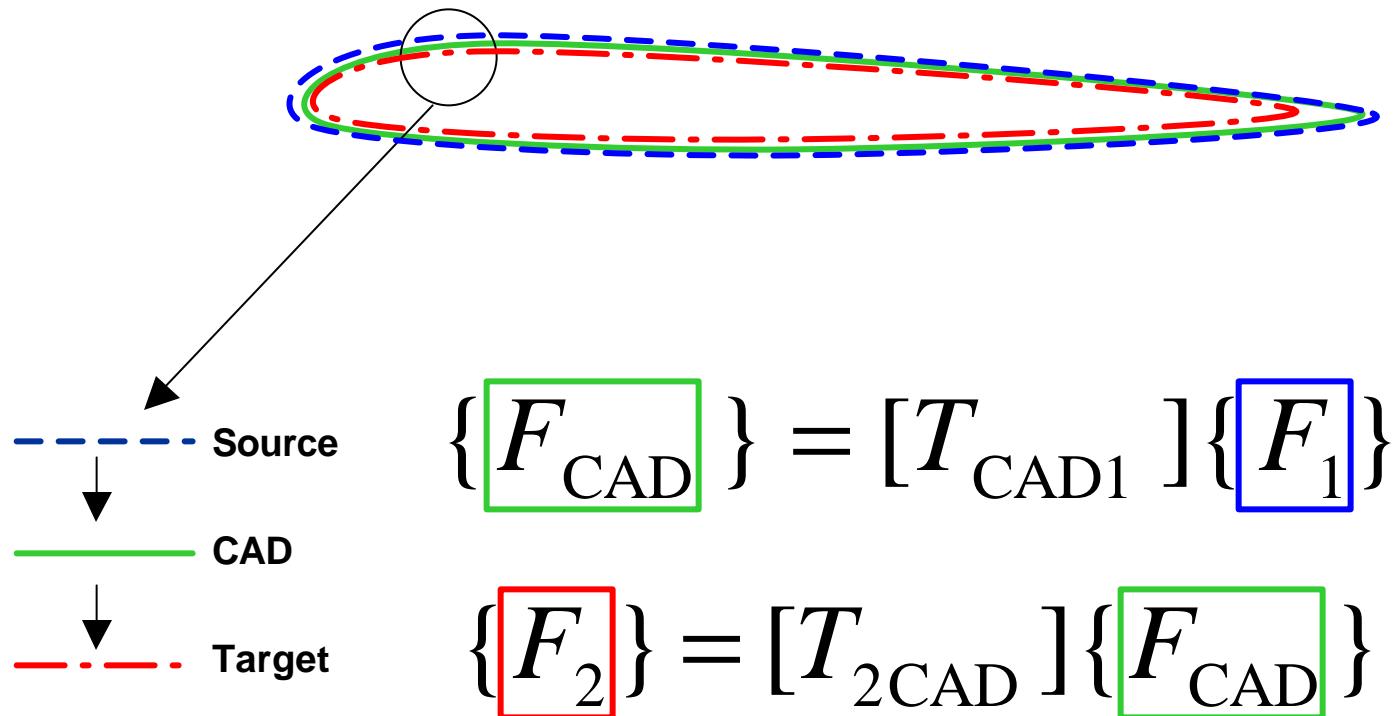
$$\{\bar{F}_S(V_i)\} = [T_{SF}] \{\bar{F}_F(V_i)\}$$

If $[T_{SF}]$ is independent of V_i

$$\left\{ \frac{\partial \bar{F}_S}{\partial V_i} \right\} = [T_{SF}] \left\{ \frac{\partial \bar{F}_F}{\partial V_i} \right\}$$

Unified Approach to Modeling Multidisciplinary Interactions

(CAD + Transformation Matrix)



Available Techniques

§ **Infinite-plate spline (IPS)**

§ **Multiquadric biharmonic (MQ)**

§ **Thin-plate spline (TPS)**

§ **Finite-plate spline (FPS)**

Ü **Nonuniform rational B-spline (NURBS)**

(Samareh¹⁴)

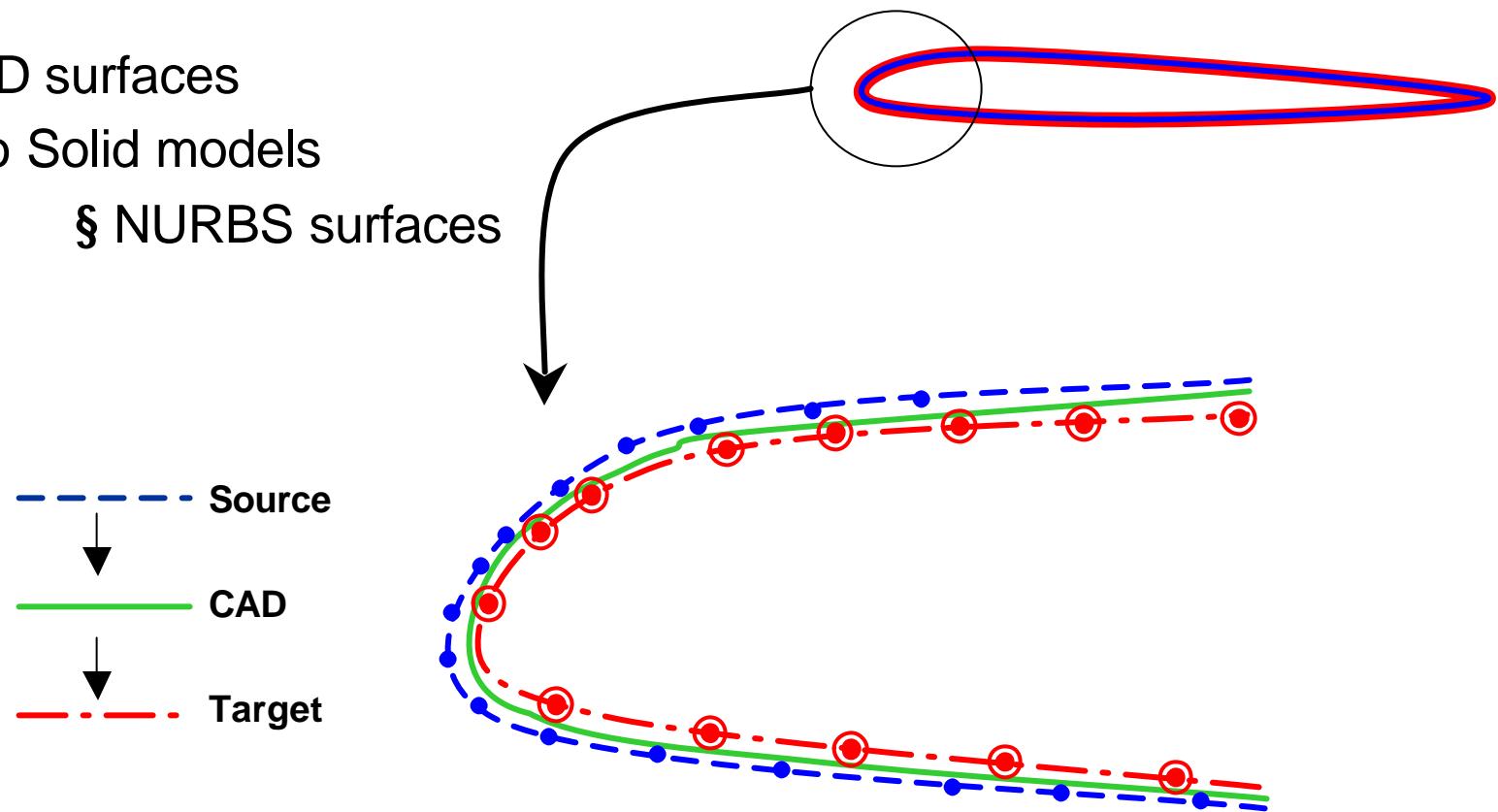
Ü **Inverse isoparametric mapping (IIM)**

Interpolation-based algorithm (IBA)

(Farhat²¹, Cebral, Löhner^{7,20})

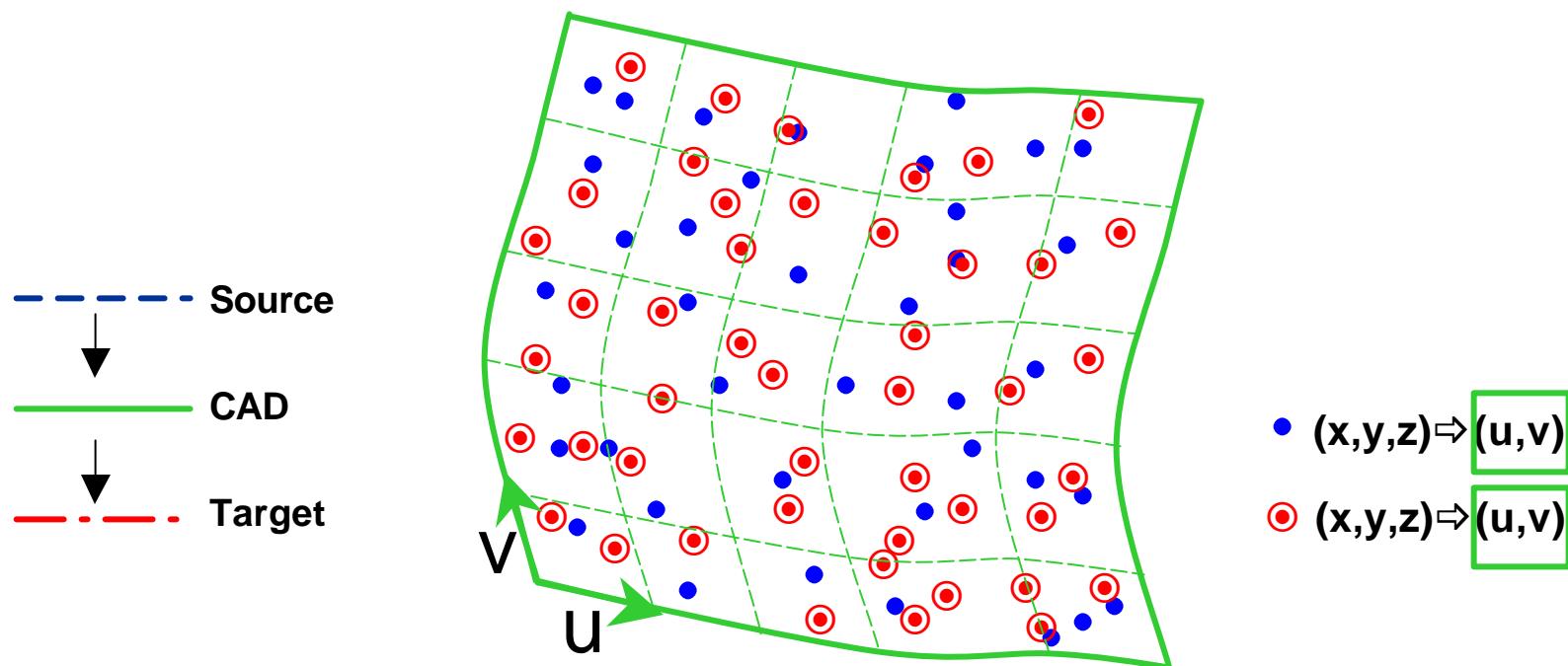
CAD Surface Model (NURBS)

- CAD surfaces
 - Solid models
 - § NURBS surfaces



NURBS (Cont.)

- Project all grids to CAD surfaces
- Fit the source data with a NURBS
- Use normal equations to form transformation matrix



NURBS (Cont.)

• $(x,y,z) \Rightarrow (u,v)$

$$f_1(u, v) = \sum_i^I \sum_j^J B_{i,p}(u) B_{j,q}(v) \tilde{F}_{ij} = [C] \{\tilde{F}\}$$

↓
Refs. 14-16

$$\{\tilde{F}\} = [T_{C1}] \{F_1\}, \text{ where } [T_{C1}] = [C^T C]^{-1} [C]^T$$

◎ $(x,y,z) \Rightarrow (u,v)$

$$f_1(u, v)$$

$$F_2$$

$$\{F_2\} = [T_{21}] \{F_1\}$$

Pros/Cons of NURBS

Pros

- Smooth
- Direct CAD connection

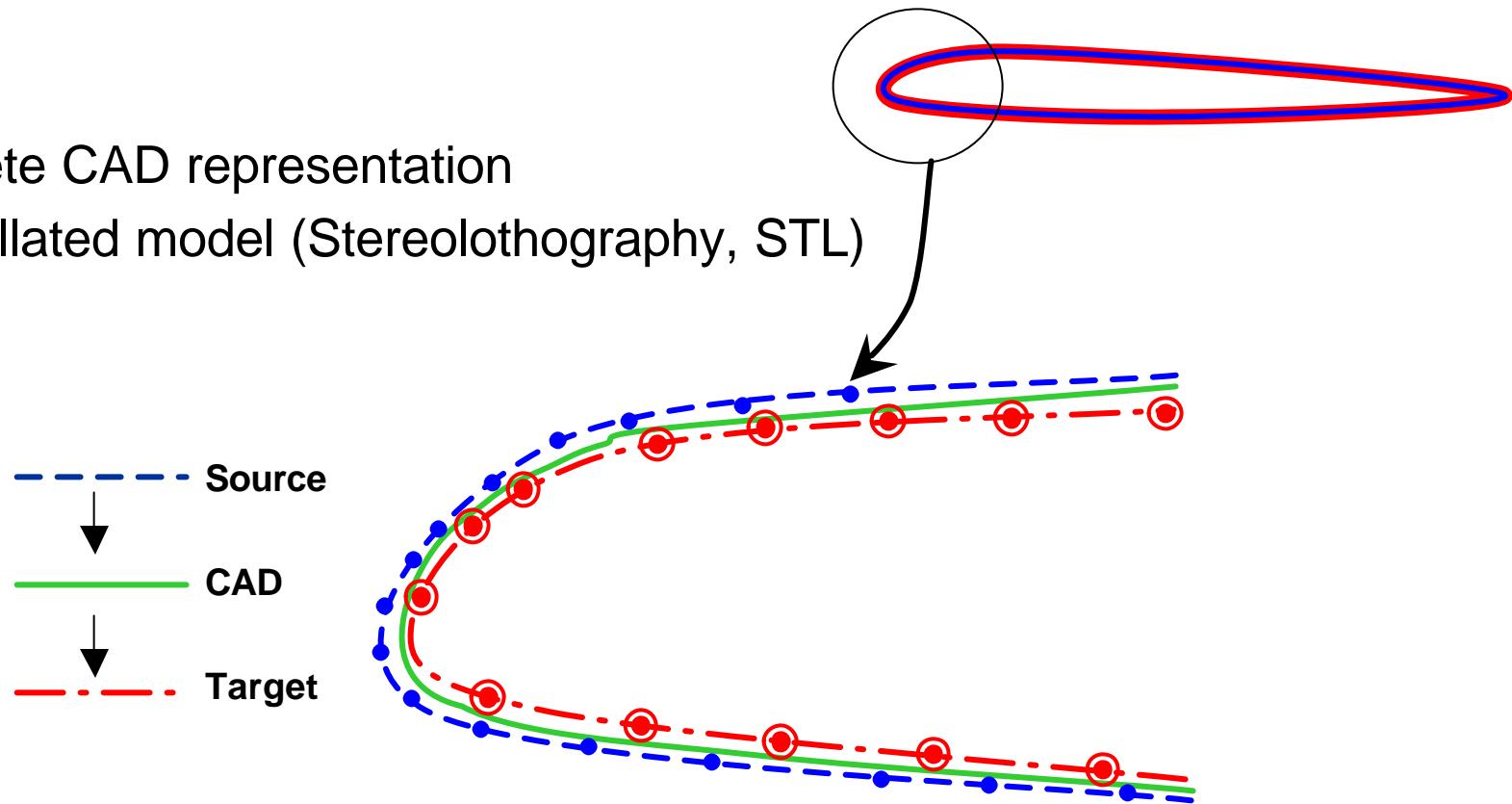
Cons

- No guarantee for conservation
- Possible discontinuity across CAD surfaces
- Difficult to implement

Interpolation-Based Algorithm (IBA)

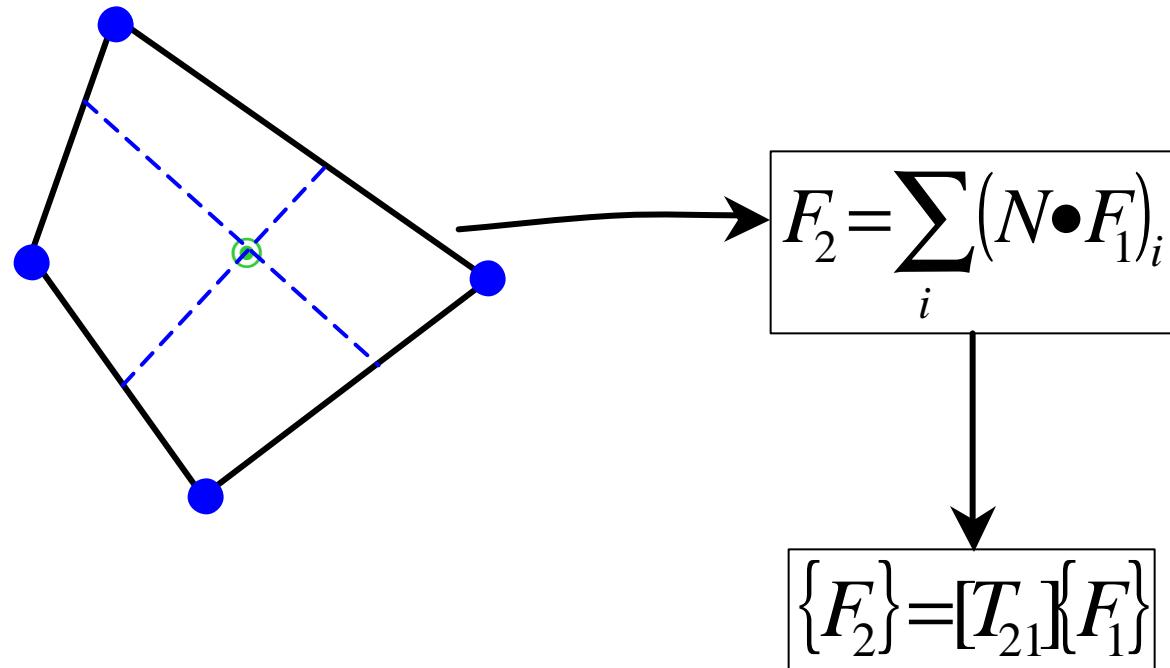
(nearest neighbor interpolation)

- Discrete CAD representation
- Tessellated model (Stereolithography, STL)



Interpolation (Cont.)

- Project all grids to CAD tessellated model
- Use interpolation coefficients to form transformation matrix



Pros/Cons of IBA

Pros

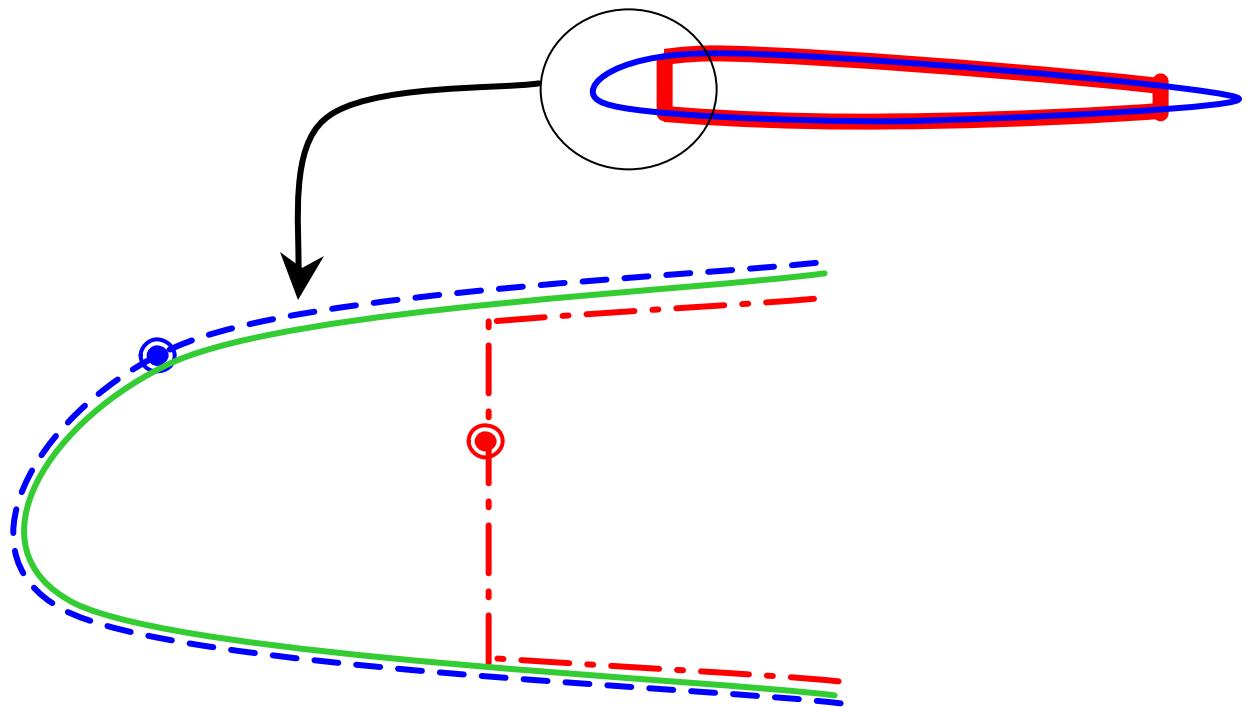
- Can guarantee conservation
- Simple to implement

Cons

- Possible discontinuity

Grids With Different levels of Geometry Details

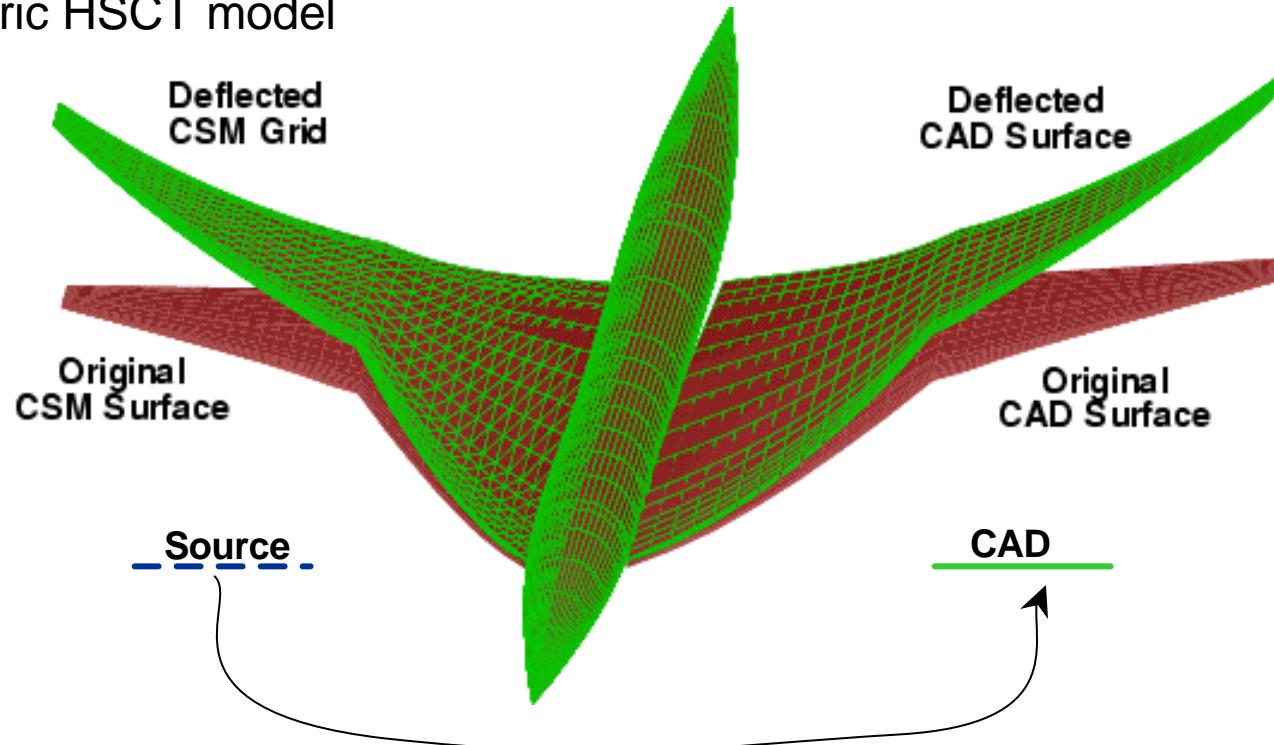
- Discipline models often have different levels of geometry details
- The target data is either extrapolated or approximated



Aeroelastic Deflection (NURBS)

CSM \rightarrow CFD

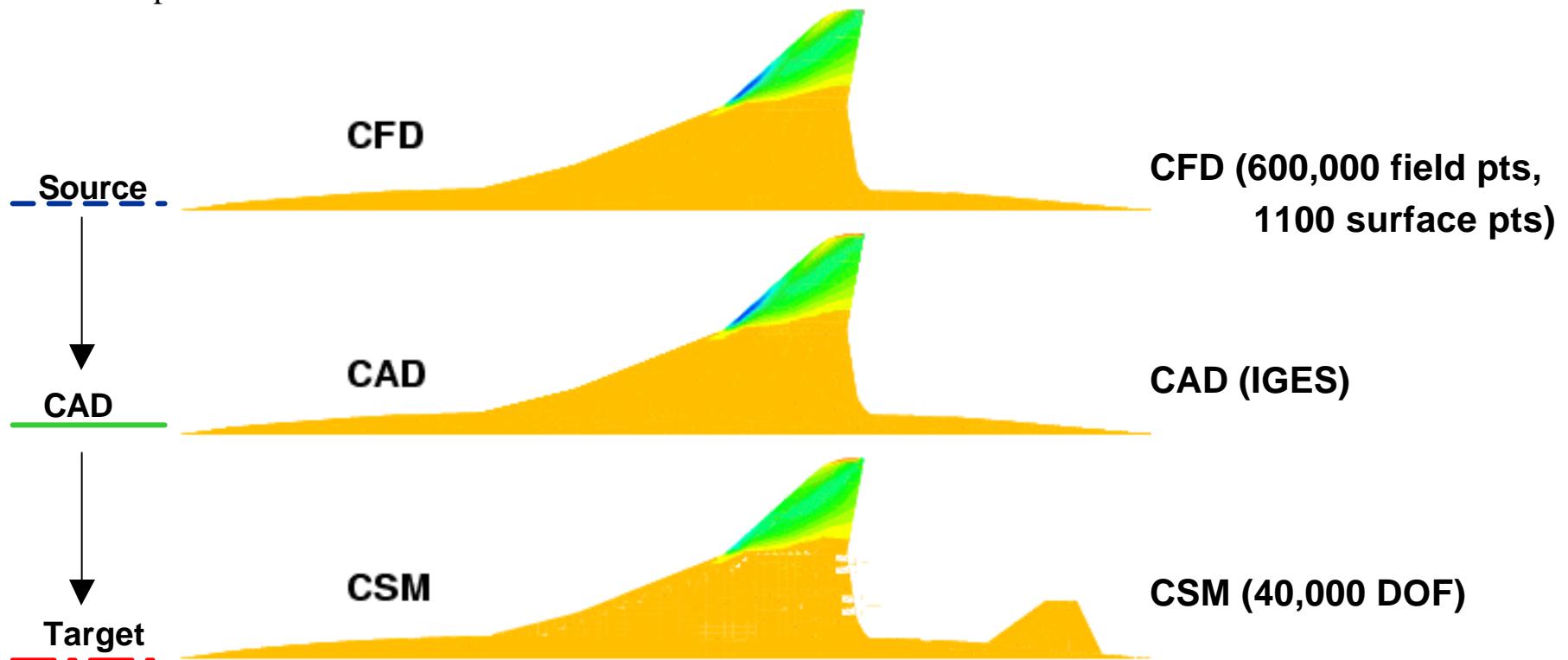
- Deflection transferred from CSM to CAD
- Generic HSCT model



Sensitivity Derivative (IBA)

CFD \rightarrow CSM

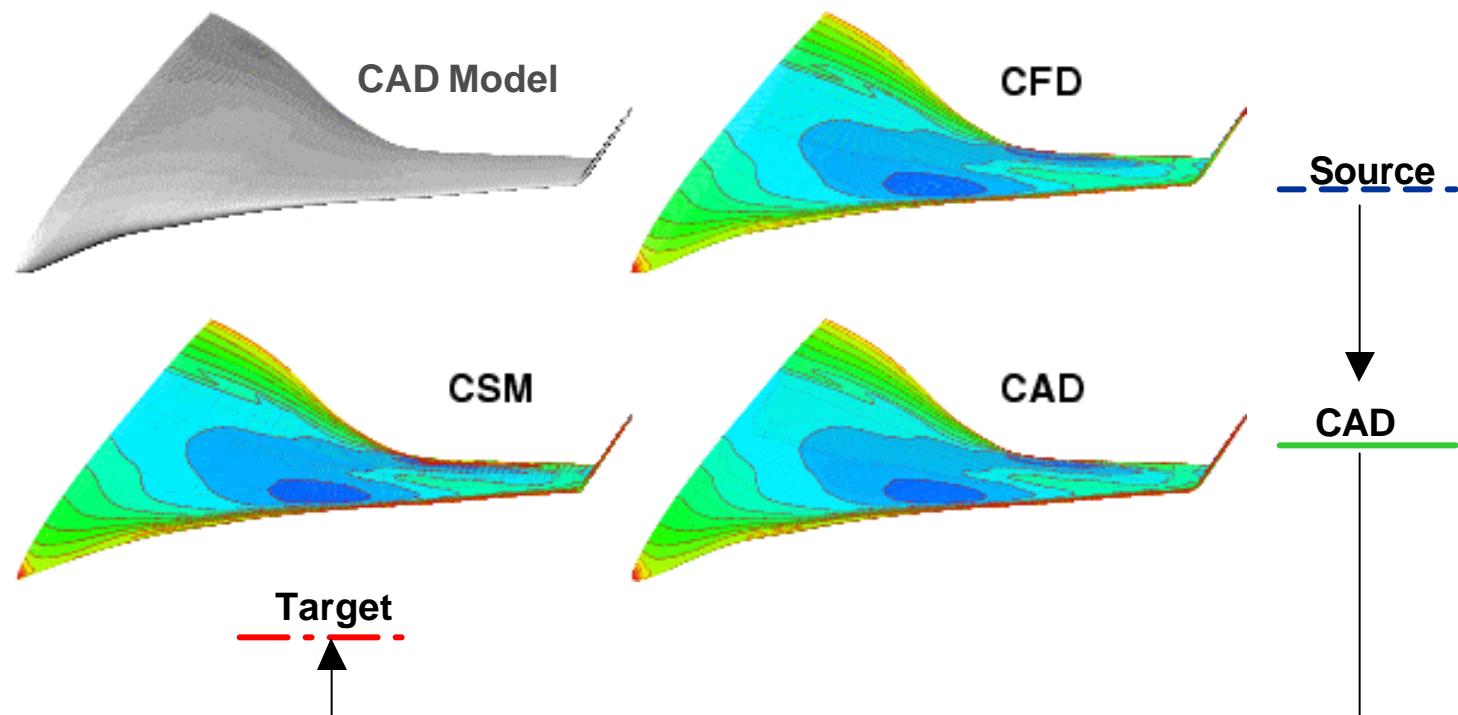
- HSCT model
- $\frac{\partial P}{\partial \text{Sweep}}$ transferred from CFD to CAD to CSM



Pressure (IBA)

CFD → CSM

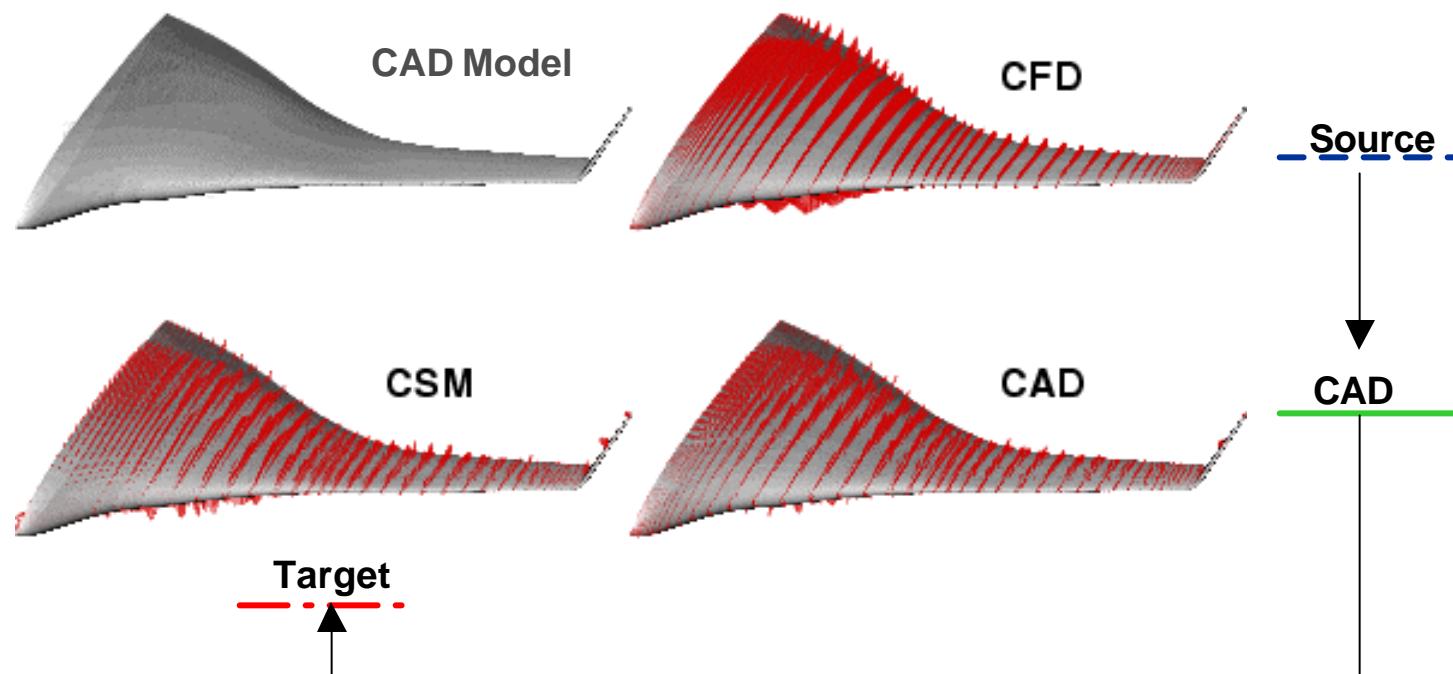
- BWB model
- Pressure transferred from CFD to CAD to CSM



Loads (IBA)

CFD → CSM

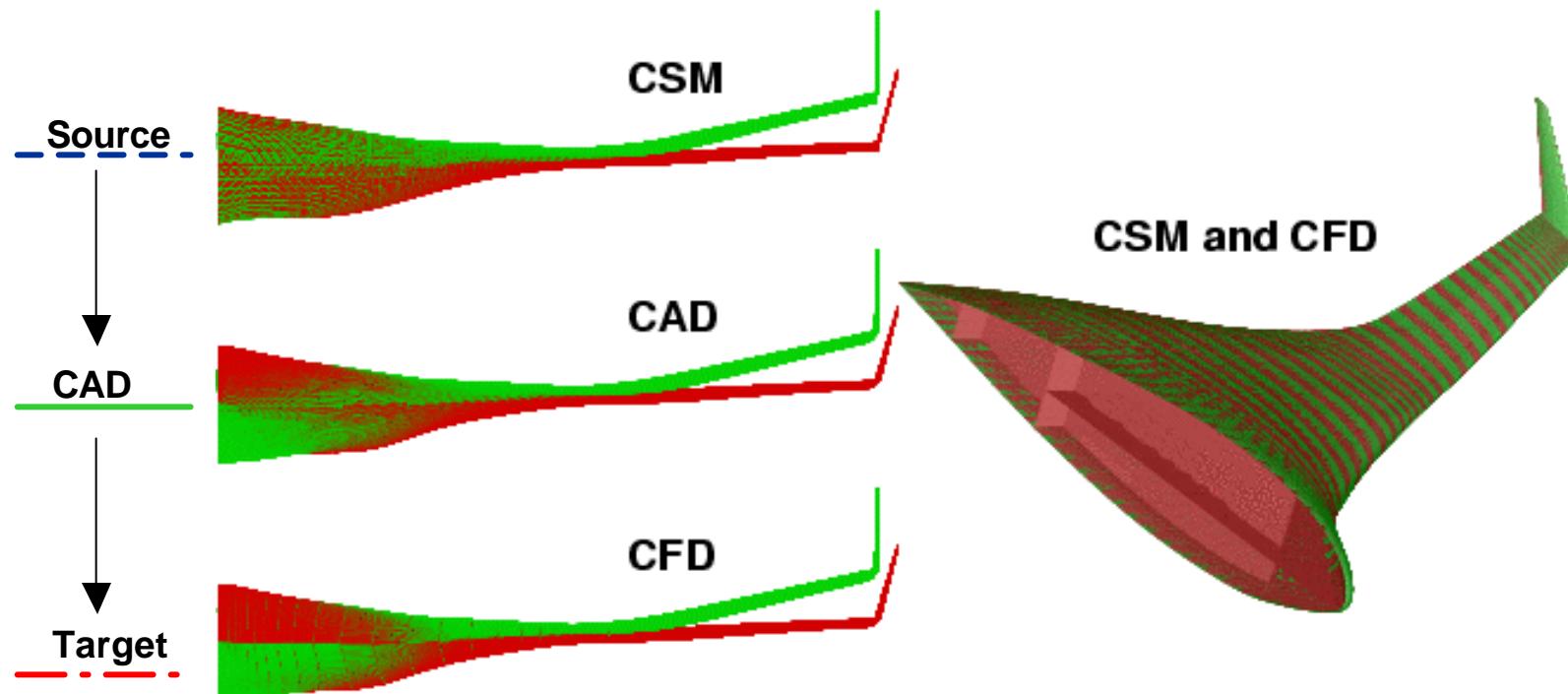
- BWB model
- Loads transferred from CFD to CAD to CSM
- Conservative



Deflection (IBA)

CSM → CFD

- BWB model
- Deflection transferred from CSM to CAD to CFD



Summary

- Presented a unified CAD-based approach
 - Unified approach reduces # of interactions (from $n(n-1)$ to $2n$)
 - Same code can be used for various transfer processes
- Presented results for high-speed civil transport and blended-wing body

Future Work

- Perform quantitative comparisons of NURBS and IBA within a CAD environment
- Investigate and formulate conservative NURBS approach
- Investigate and develop a smooth IBA
- Apply unified approach to other disciplines (e.g., aerothermal) and new applications (reusable launch vehicle & joined-wing demonstrator)
- Assess applicability of unified approach within an industrial setting